An update from the Diffraction and Tagging PWG

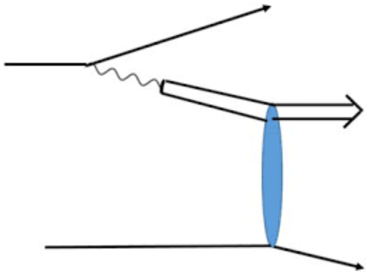
D & T convenors: Wim Cosyn, Or Hen, Douglas Higinbotham, Spencer Klein and Anna Stasto

FIU EIC Users Group Meeting, July 15-17, 2020

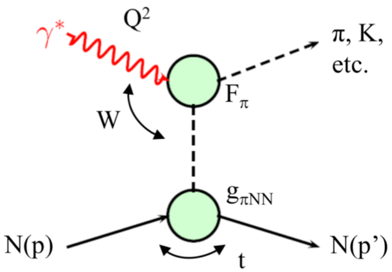
- Group Overview
- Highlights of recent work
  - (since Pavia)
- Conclusions

"D & T" covers a broad range of physics topics

- Incoherent photoproduction and electroproduction of vector mesons
  - Protons, light ions (d, ^{4}He…) and heavy ions
  - Key HI question: coherent/incoherent separation?



- Short range nucleon-nucleon correlations
- π/K structure functions
- Inclusive Diffraction & diffractive structure functions
- Diffractive dijets
- Meson spectroscopy (including $\gamma\gamma$) and 'Backward' (u channel) meson production



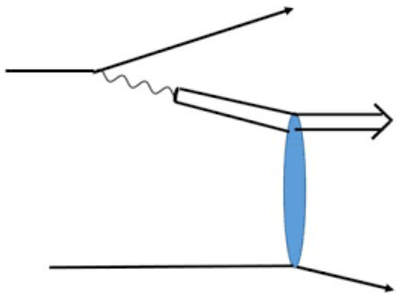
- Nucleon fragmentation
- DIS, SIDIS with spectator tagging
- Elastic (ep,eD) scattering

Some topics overlap with other groups

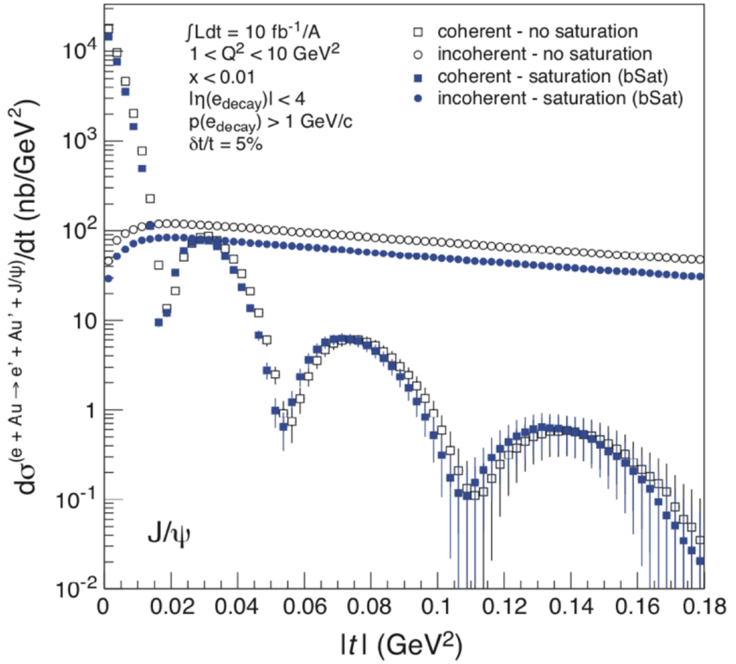
Status

- Topics are at different stages of development
  - For some, we have good simulations
  - For others, we have good physics models
  - Still others are at an earlier stage
    - There are some critical open physics questions, including those that impact detector requirements
  - For some channels, background estimates are needed to determine the required detector resolution
  - These are also at different stages of development
- We are manpower limited; not all of the schedules are consistent with determining detector requirements in the next few months

Vector meson photoproduction and electroproduction



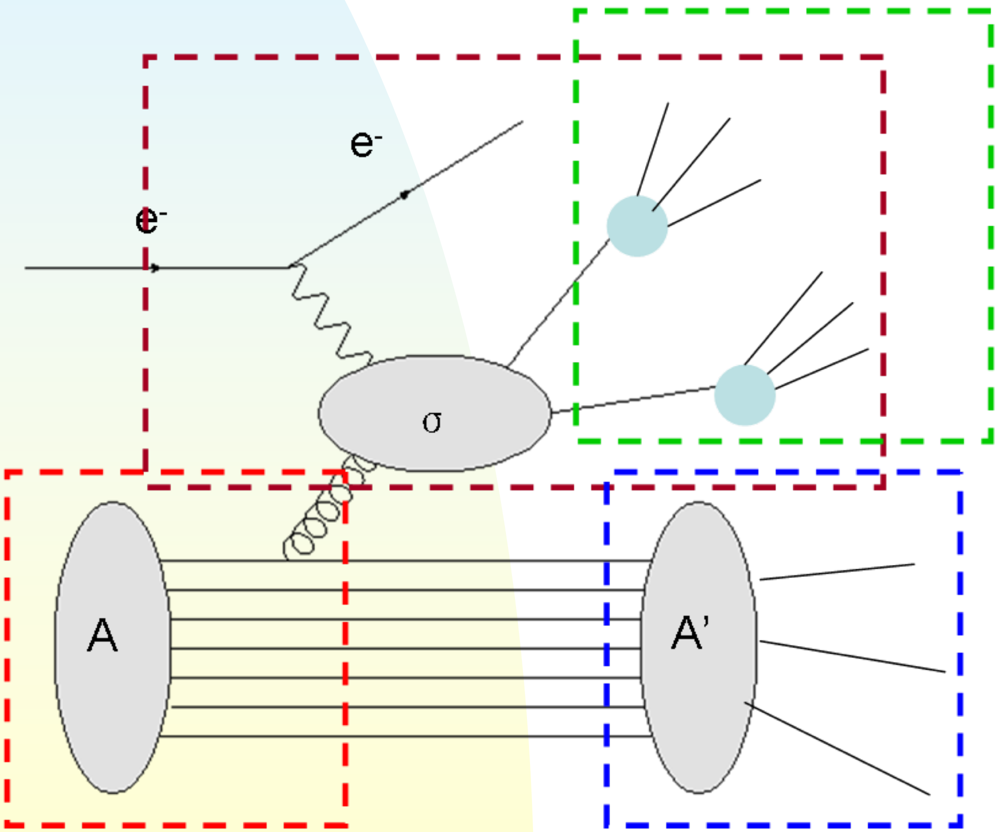
- Coherent photoproduction (in exclusive group) and incoherent photoproduction (in diffraction and tagging) differ only in the presence of nuclear breakup.
- In Good-Walker paradigm:
  - Coherent photoproduction is sensitive to the average nuclear configuration
    - dσ/dt maps out parton positions, ala GPDs
    - Spatial distribution of shadowing
  - Incoherent photoproduction is sensitive to fluctuations, in nuclear positions and also to the presence of gluonic hot spots
- Good separation is critical!
  - Need to understand incoherent final states



The BeAGLE Monte Carlo

- Our main tool for simulating nuclear breakup in eA interactions
  - Nuclear excitation, w/ decay by n, p, γ emission
- Tuned w/ FNAL E665 data

Mark Baker



A hybrid model consisting of DPMJet and PYTHIA with nPDF EPS09.

Nuclear geometry by DPMJet and nPDF provided by EPS09.

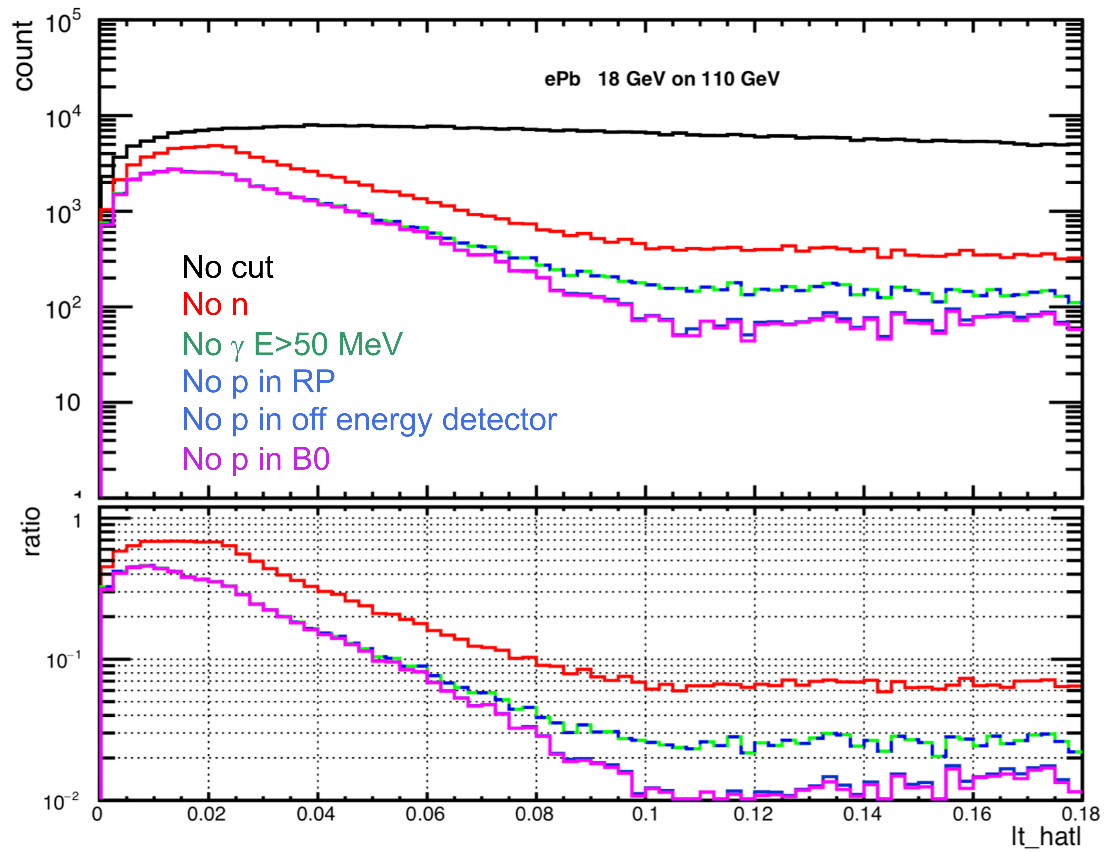
Parton level interaction and jet fragmentation completed in PYTHIA.

Nuclear evaporation (gamma dexcitation/nuclear fission/fermi break up) treated by DPMJet

Energy loss effect from routine by Salgado&Wiedemann to simulate the nuclear fragmentation effect in cold nuclear matter

BeAGLE and tagging heavy ion breakup

- Neutron emission is dominant -> ZDC
- Proton emission is secondary -> proton spectrometer
- Nucleon-free (~ MeV photons) fraction depends on |t|
  - ~2% at large t, increasing as |t| decreases
  - # of γ, energies, poorly known
  - Only ½ of photons are Lorentz boosted



Plot from Wan Chang, in the exclusive group

Nuclear structure at low |t|

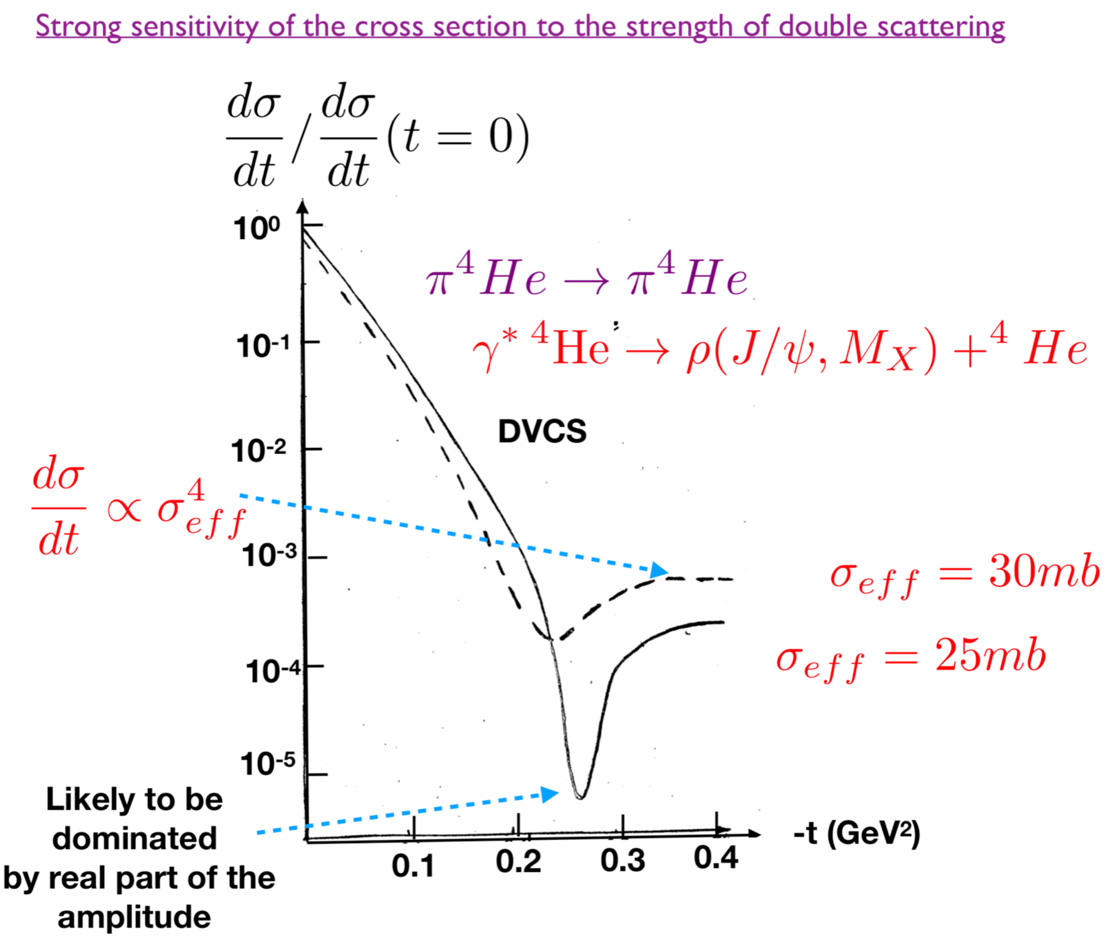
- Reactions like $^{208}Pb \to {}^{207}Pb + n$, $^{207}Tl + p$, $^{197}Au \to {}^{196}Au + n$ are endothermic
  - Threshold energy required 5-8 MeV
  - If one assumes that a single nucleon recoils, nucleon emission from Pb is impossible for $|t|<0.015$ GeV^2
- Low energy (~ 5 MeV) nuclear excitations must go to specific excited (shell-model) states
  - The lowest lying state for ^{208}Pb is at 2.6 MeV
    - No accessible states whatsoever for lesser energy transfer
      - Incoherent cross-section=0
      - For single-nucleon recoil, this is $|t|<0.005$ GeV^2
  - The lowest excited state for ^{197}Au is at 77 keV
    - Long-lived (1.9 nsec, $\gamma\beta c\tau$=118 m), so will escape any EIC detector
      - Indistinguishable from coherent production.
    - Two other states below 300 keV
      - 50 MeV lab-frame energy threshold << 100% efficient
  - Lead and gold are quite different!

$d\sigma_{incoherent}/dt$ at small |t|

- $d\sigma_{incoherent}/dt$ must drop with decreasing |t| as various final states become kinematically inaccessible.
  - Above kinematic thresholds, a gradual turn-on is expected.
- It seems hard to measure (or calculate) incoherent photoproduction at small |t|. Distinguish between coherent and incoherent production is tricky.
- This has implications for the Good-Walker paradigm, which relates $d\sigma_{incoherent}/dt$ to event-by-event fluctuations in the nuclear state (e. g. nucleon position and gluonic hot spots).
  - At small |t|, nuclei are better described using shell model orbitals than nucleon positions.

Coherent photoproduction on light ions

- 4He is particularly interesting because double-scattering is likely
  - Clean test of multiple scattering mechanism

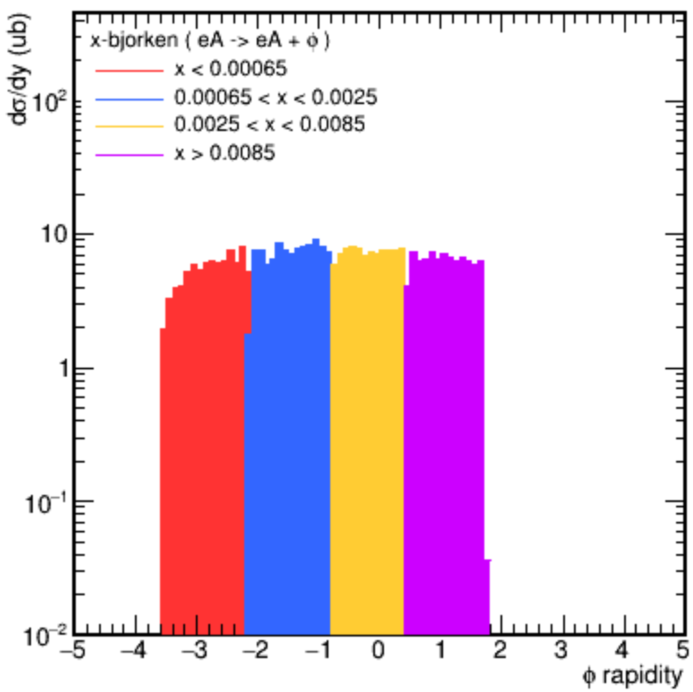


Tagging scattered light ions

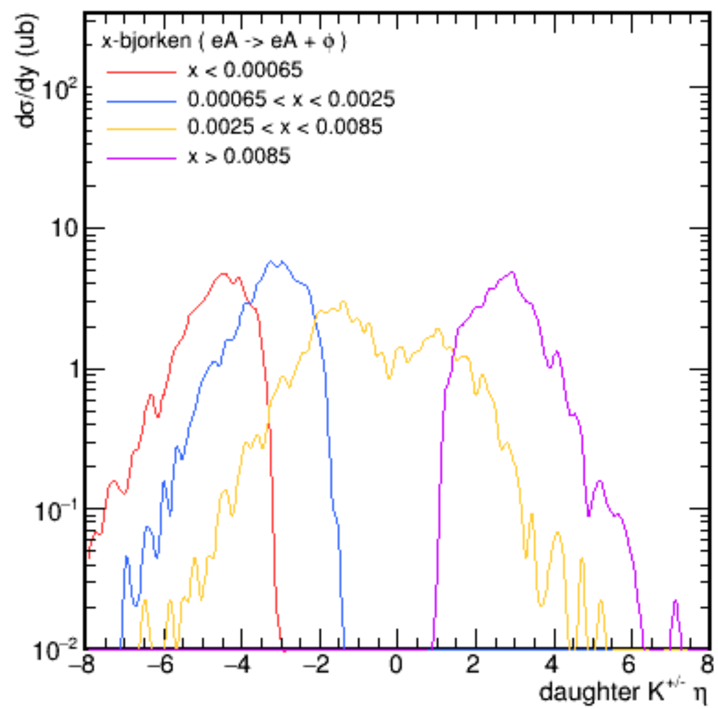
- For many applications (nuclear imaging, coherent phenomena), it is highly desirable (and possible) to detect the scattered ion in coherent photoproduction
  - Improved separation of coherent and incoherent photoproduction
    - $\sigma_{coherent} << \sigma_{incoherent}$
  - Improved measurement of reaction kinematics
- Desired kinematic coverage:
  - $10^{-4} < X < 10^{-1}$ i. e. down to small fraction electron energy loss
  - $0 <$ ion $p_T < 700$ MeV/c
  - Limited by beam divergence; some of these ions may remain in the beam
- Desirable for as many ions as possible (i. e. up to the largest possible A)

Vector meson reconstruction

- J/ψ, ψ', Υ->ee are fairly easy to reconstruct ($\mu\mu$ channel?)
- Φ->K^+K^- is hard because the kaons are so soft
  - P=135 MeV/c (β~0.2) in ϕ rest frame
- 18 GeV e on 100 GeV Au – eSTARlight simulation
- Bjorken x maps to rapidity – need wide coverage for low x



Φ rapidity



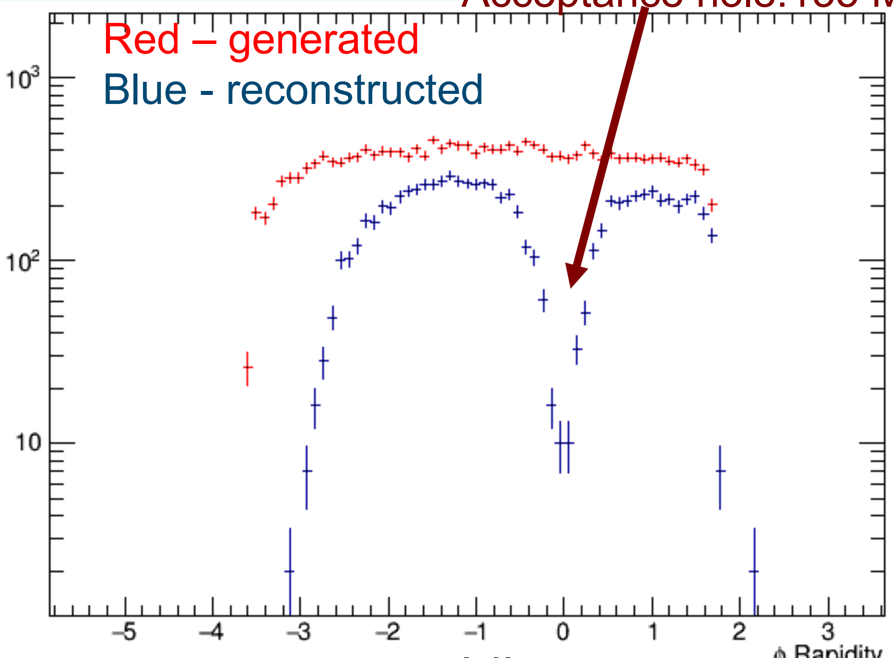
Kaon pseudorapidity

Sam Heppelman

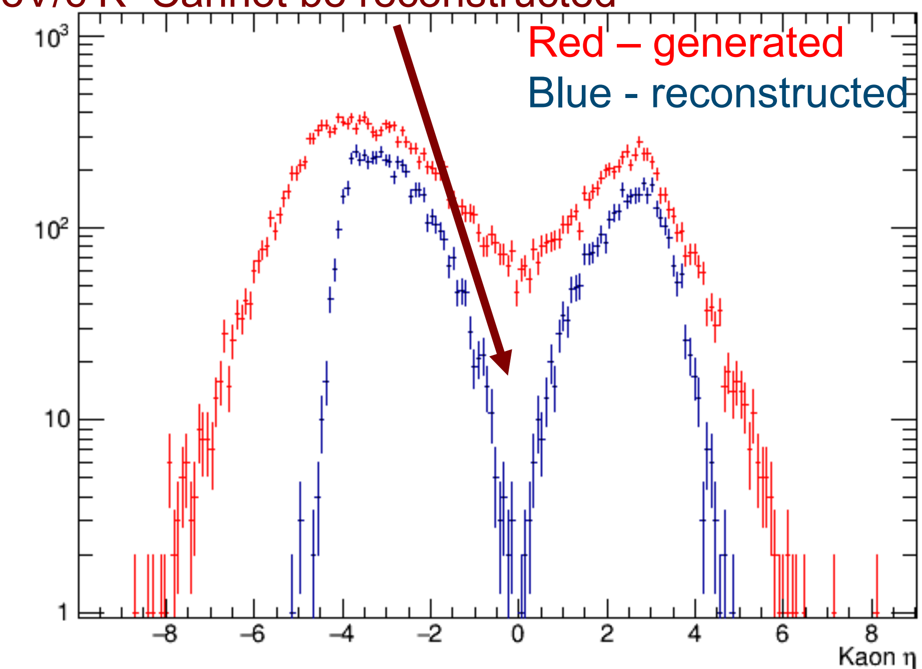
ϕ detection efficiency

- All-silicon tracker, with 6 barrel layers and 6 endcap disks/side
  - eSTARLIGHT → EICRoot
- 18 GeV e on 100 GeV Au
- All Q^2, but dominated by low Q^2
- Acceptance hole at mid-rapidity (for low Q^2)
- Other ϕ decay modes seem tough

Acceptance hole:135 MeV/c $K^{\pm}$ Cannot be reconstructed

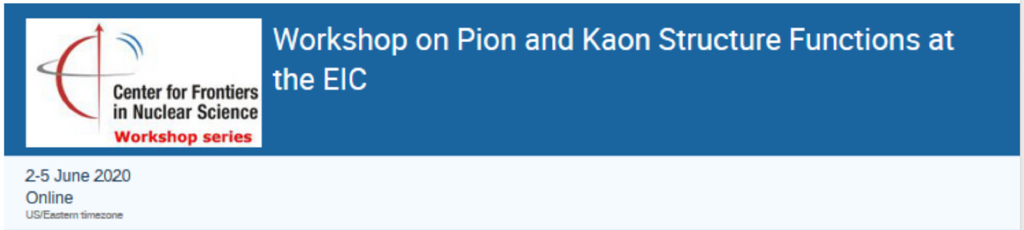


Φ rapidity



Kaon pseudorapidity

EIC Meson Structure Functions



Meson SF Working group:

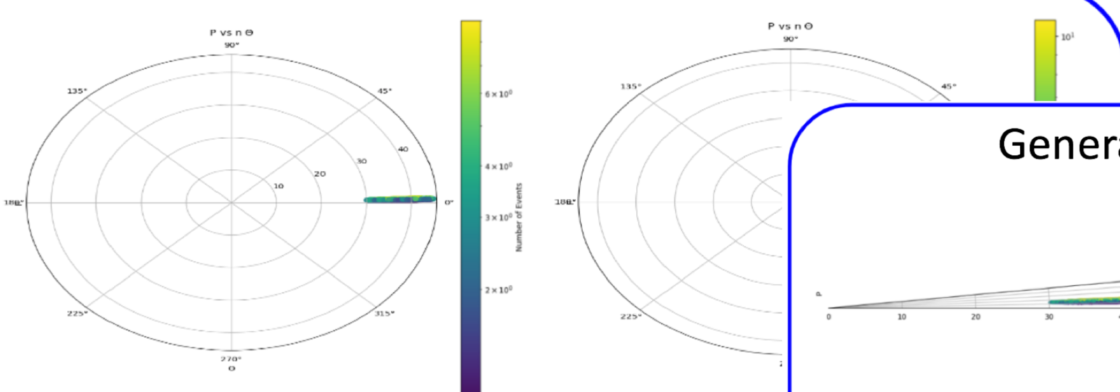
- 20+ researchers from theory, experiment, lattice, global fitting
- Series of meetings and workshops – most recent CFNS (138 participants registered; Attendance: ~100/day; Zenodo community and summary paper in preparation)

Physics Deliverables: pion/kaon structure function plots, pion form factor plot

Physics Objects and Kinematics – fast simulations to determine detector requirements

- scattered electron
- measure pion and tagged neutron -> pion form factor
- measure "X" and tagged neutron -> pion structure function
- measure "X" and tagged Lambda/Sigma -> kaon SF

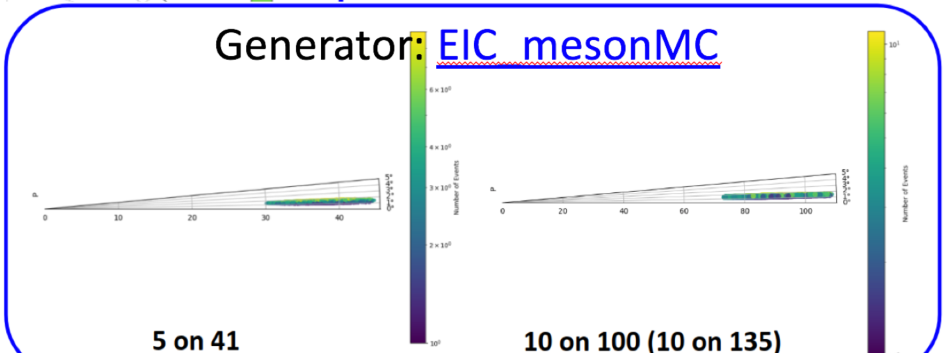
Tanja Horn &
SF working group



5 on 41

10 on 100 (1

Generator: EIC_mesonMC



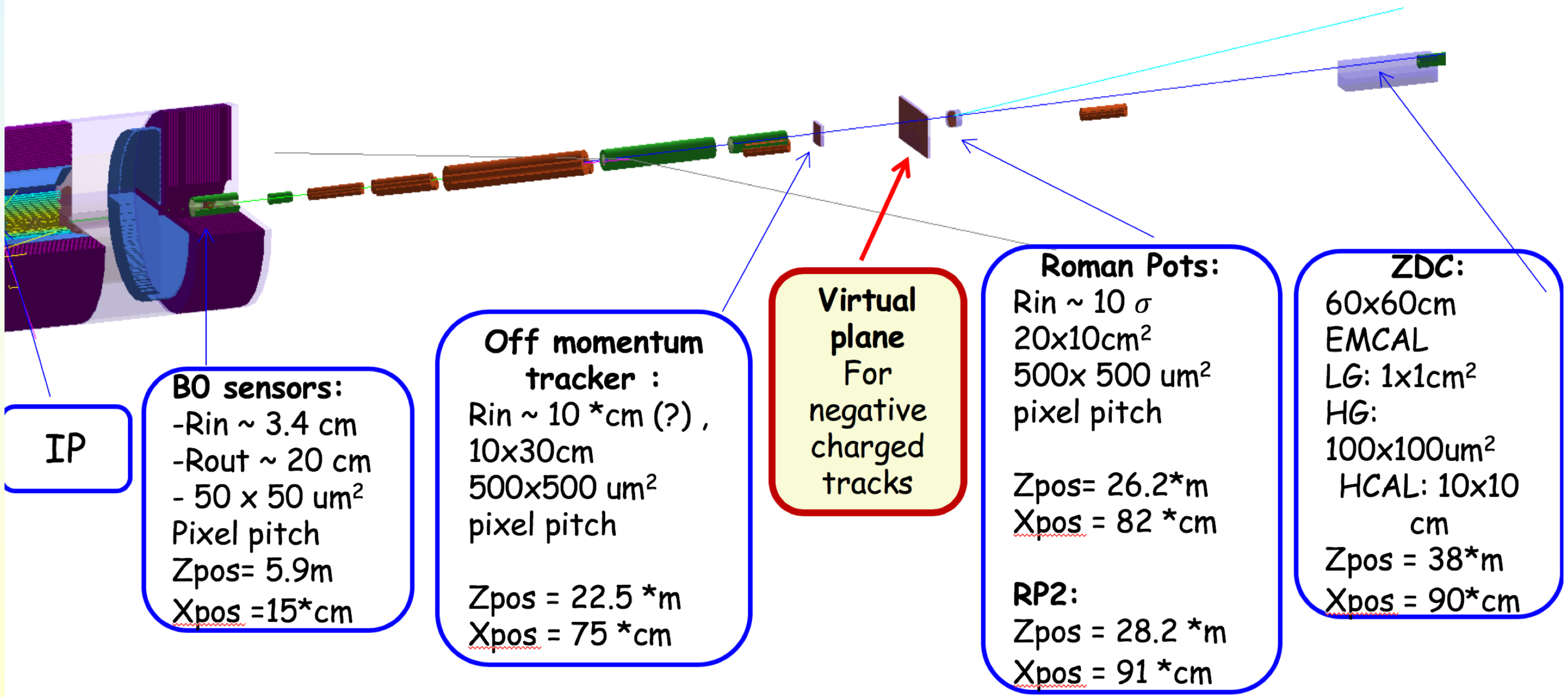
5 on 41

10 on 100 (10 on 135)

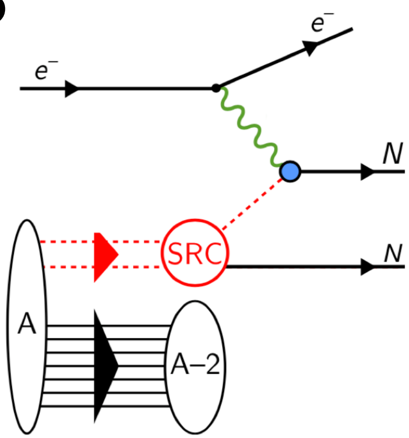
EIC Forward Beamline Elements to tag Meson Structure

Progress since the Pavia Workshop

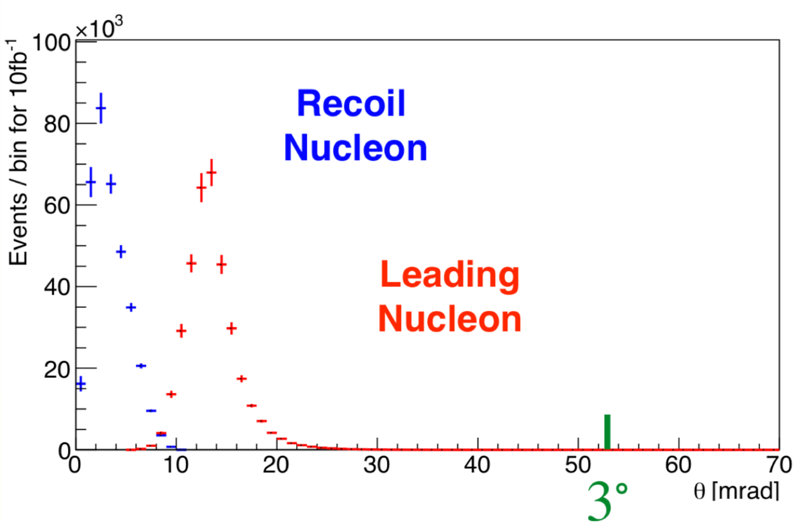
- Defined most of the requirements for the forward beamline elements to tag meson structure.
- Working on defining the "Virtual Plane", which is required to identify negatively charged tracks.

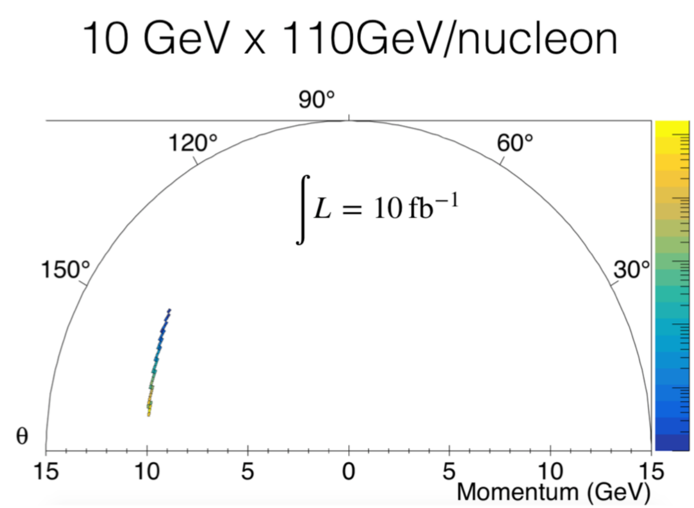


Short-range correlations in eC collisions



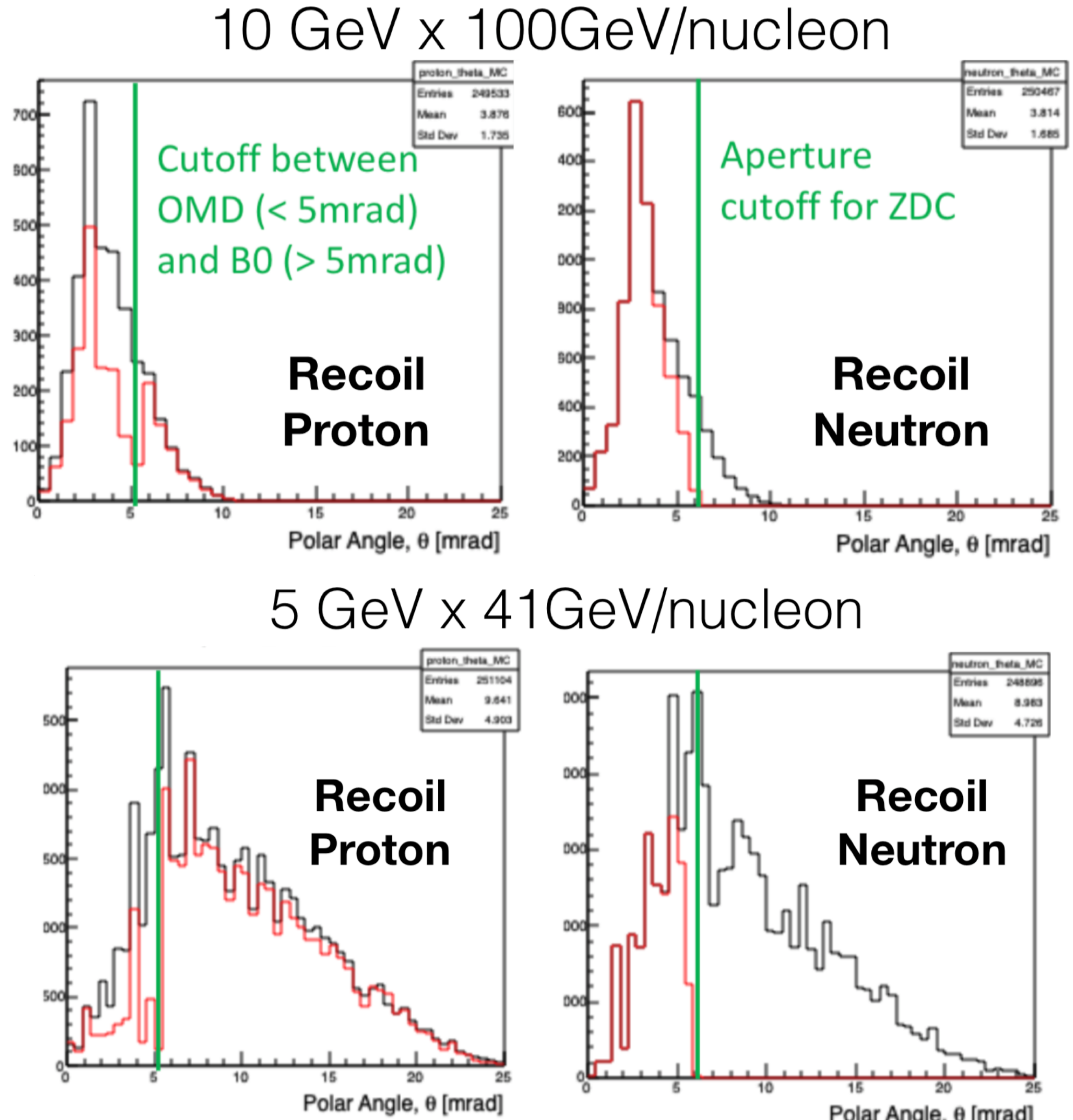
- Study short-range nucleon-nucleon correlations
  - Ideally np (dominant), nn, and pp pairs
- Studies for 10X100 GeV/n and 5X41 GeV/n
- Simulated with GCF-QE + BeAGLE
- Nucleons are scattered at small angles
  - Θ_{recoil} ~ few mrad< $\Theta_{leading}$~ 15 mrad for 10*110 GeV collisions





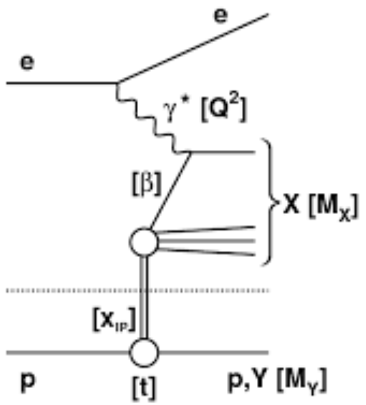
Acceptance for short range correlations in eC

- EicRroot simulations Off-momentum detectors and B0 important for recoil protons
- Limited ZDC acceptance: leading neutrons not accessible
- eD collisions require similar acceptances as eC



The diffractive longitudinal structure function F^D_L

- $F_L(x,Q^2)$ is the structure function that is related to the interaction of longitudinally polarized (virtual) photons. $F^D_L(\xi,\beta,Q^2)$ is its diffractive counterpart
  - Requires measurement of hadronic mass, and presence of rapidity gap



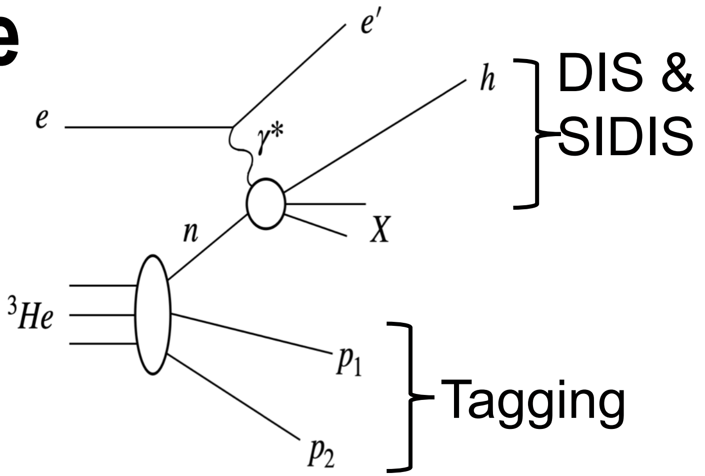
- F^D_L is sensitive to gluon component of Pomeron
- Studied by comparing cross-sections at different collision energies into same detector acceptance

$$\frac{d^2\sigma}{dxdQ^2} = \frac{2\pi\alpha^2}{Q^4 x} \cdot [(2(1-y)+y^2)F_2(x,Q^2) - y^2 F_L(x,Q^2)].$$

- Initial study considered 18 collision energies
  - To map our acceptance in ξ,β,Q^2
  - 5,10, 18 GeV electrons on 41, 100, 120,165, 180, 275 GeV
    - 18 collision energies are a lot – are all needed?

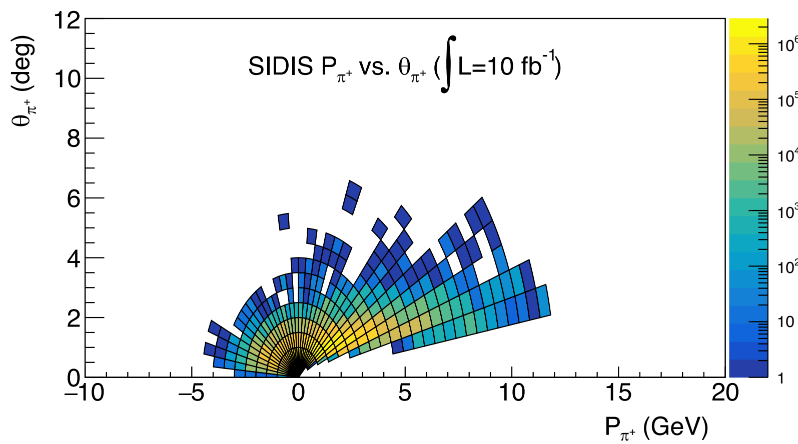
Spectator tagging in inclusive and semi-inclusive DIS of ^3He

- Measurement of structure functions F_L, F_2 and g_1 (for polarized beams), and of TMD quark distributions
- Spectator tagging provides control over the initial nuclear configuration.
  - Tagging a neutron allows the bound proton SF to be probed
  - Tagging a d gives access to the neutron
- CLAS version of SIDIS MC based on PEPSI
- Work on adding nuclear Fermi motions, distributions of spectator nucleons
- Goal: understand the accessible kinematic range and statistical uncertainties



$E_e = 5$ GeV and $E_{3He} = 41$ GeV/nucleon

Inclusive DIS cuts: $W^2 > 4$ GeV^2, $Q^2 > 2$ GeV^2



Ivica Friscic, Dien Thi Nyugen and Jackson Reeves Pybus

Toward detector requirements

- Detector requirements are emerging from parts of the diffraction and tagging group
- For vector meson reconstruction
  - Large pseudorapidity (at least $|\eta<4|$) acceptance, to cover the full Bjorken-x range
  - $\Delta p/p \sim 1\%$ at 5 GeV required to separate Υ states
  - Mid-rapidity $\phi \to K^+K^-$ photoproduction produces 135 MeV/c kaons
- For many purposes (vector mesons, short range correlations…)
  - Full kinematic coverage for downstream protons and neutrons
  - Detailed requirements & designs from meson structure function group
- To separate coherent and incoherent VM production
  - For heavy ions, downstream photon detection, down to ~ < 100 MeV
  - For light ions, detection of intact ions with small energy loss & P_T

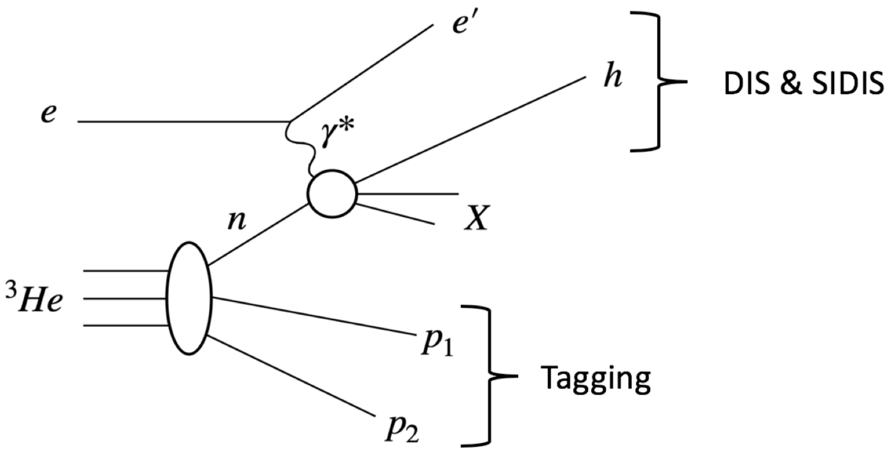
Conclusions

- Good progress on some topics since Pavia.
- There are conceptual/practical difficulties in achieving the required separation between coherent and incoherent photoproduction envisaged in the 2012 White Paper.
  - There are large uncertainties in how the energy deposited in a recoiling nucleus will manifest itself.
- The group has a strong focus on tagging forward nucleons, and possibly photons. This requires the largest possible solid angle coverage.
  - The meson structure function group is studying fairly detailed designs for forward spectrometers
- Good progress on detector requirements in some areas.


Questions?
Pregunte?
שאלות?
Pytania?
Frage?
أسئلة؟
Pātai?
mga tanong?
有問題嗎？

Backup

Polarized 3He: DIS, SIDIS and Tagging measurements



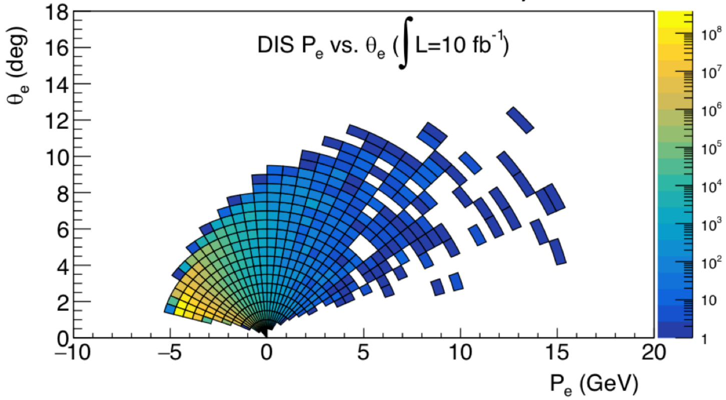
At the moment, work is being carried to improve generated events by adding:

- smearing due to nucleon Fermi motion effects
- distributions of the spectator nucleons -> exploring possibility to study "tagged DIS" at EIC

Physics goals: Perform an estimate of the statistical uncertainties of the structure functions and TMDs at kinematics accessible by EIC

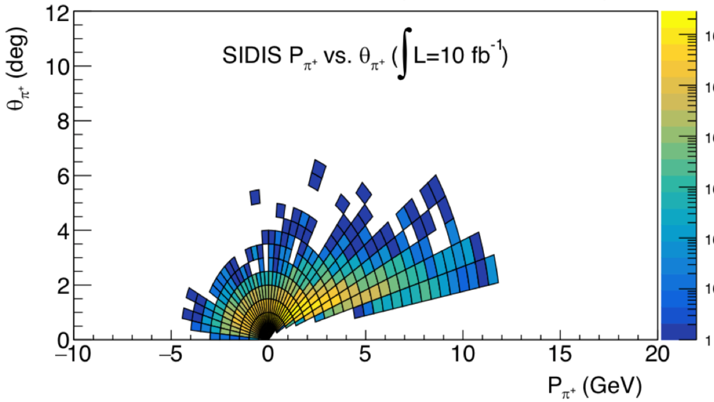
E_e = 5 GeV and E_{3He} = 41 GeV/nucleon

Inclusive DIS cuts: $W^2 > 4$ GeV^2, $Q^2 > 2$ GeV^2



For example: ^{3}He(e, e'π^+)X

SIDIS cuts: W2 > 4 GeV2, Q2 > 2 GeV2, Z > 0.3



MIT-LNS: Ivica Friščić, Dien Thi Nguyen, Jackson Reeves Pybus

^{208}Pb

- No low-lying nuclear states
- First state, 2.6 MeV, corresponds to p_T= 70 MeV
  - No accessible incoherent excitation for p_T < 70 MeV/c
    - Marginally accessible: 3 hbar angular momentum needed.

#	Nuclide	E_x [keV]	J^{π}_{order}	Band	$T_{1/2}$	$T_{1/2}$ [s]	Decay modes BR [%]	Isospin	μ [μ_N]	Q [b]	Additional data	Comments
1	$^{208}_{82}Pb_{126}$	0	0+		STABLE							
2	$^{208}_{82}Pb_{126}$	2614.522 *10*	3-		16.7 ps *3*	1.67E-11			+1.9 *2*	-0.34 *15*		
3	$^{208}_{82}Pb_{126}$	3197.711 *10*	5-		294 ps *15*	2.94E-10			+0.11 *4*		El. Trans. Prob. 0.0447 *30*	
4	$^{208}_{82}Pb_{126}$	3475.078 *11*	4-		4 ps *3*	4E-12						
5	$^{208}_{82}Pb_{126}$	3708.451 *12*	5- *2*								El. Trans. Prob. 0.0241 *18*	
6	$^{208}_{82}Pb_{126}$	3919.966 *13*	6-		690 fs	6.9E-13						
7	$^{208}_{82}Pb_{126}$	3946.578 *14*	4- *2*		430 fs	4.3E-13						
8	$^{208}_{82}Pb_{126}$	3961.162 *13*	5- *3*								El. Trans. Prob. ≈ 0.0008	
9	$^{208}_{82}Pb_{126}$	3995.438 *13*	4- *3*		690 fs	6.9E-13						
10	$^{208}_{82}Pb_{126}$	4037.443 *14*	7-		690 fs	6.9E-13					El. Trans. Prob. ≈ 0.0010	
11	$^{208}_{82}Pb_{126}$	4051.134 *13*	3- *2*		326 fs *+28-21*	3.26E-13						
12	$^{208}_{82}Pb_{126}$	4085.52 *4*	2+		0.80 fs *4*	8E-16				-0.7 *3*		
13	$^{208}_{82}Pb_{126}$	4125.347 *12*	5- *4*		490 fs	4.9E-13						
14	$^{208}_{82}Pb_{126}$	4144 ? *5*	+									
15	$^{208}_{82}Pb_{126}$	4180.414 *14*	5- *5*		319 fs *35*	3.19E-13						
16	$^{208}_{82}Pb_{126}$	4206.277 *14*	6- *2*		690 fs	6.9E-13						
17	$^{208}_{82}Pb_{126}$	4229.590 *17*	2-		333 fs *28*	3.33E-13						
18	$^{208}_{82}Pb_{126}$	4254.795 *17*	3- *3*		97 fs *7*	9.7E-14						
19	$^{208}_{82}Pb_{126}$	[illegible]	[illegible]		[illegible]	[illegible]						

From https://nds.iaea.org/relnsd/vcharthtml/VChartHTML.html

Nuclear structure of ^{197}Au

- Many excited states below 1 MeV

$T_{1/2}$= 1.92 ns
$\gamma\beta c\tau$ = 118 m

7.3 s half-life
(Inaccessible due to L)

#	Nuclide	E_x [keV]	J^{π} order	Band	$T_{1/2}$	$T_{1/2}$ [s]	Decay modes BR [%]	Isospin	μ [μ_N]	Q [b]	Additional data	Comments
1	$^{197}_{79}Au_{118}$	0.0	3/2+		STABLE							
2	$^{197}_{79}Au_{118}$	77.3510 *20*	1/2+		1.91 ns *1*	1.91E-9	γ-ray					
3	$^{197}_{79}Au_{118}$	268.788 *10*	3/2+ 2		15.4 ps *13*	1.54E-11	γ-ray					
4	$^{197}_{79}Au_{118}$	279.00 *5*	5/2+		18.6 ps *15*	1.86E-11	γ-ray		+0.53 *5*			
5	$^{197}_{79}Au_{118}$	409.15 *8*	11/2-		7.73 s *6*	7.73E0	IT 100		+5.98 *9*	+1.68 *5*		
6	$^{197}_{79}Au_{118}$	502.5 *3*	5/2+ 2		1.77 ps *+19-12*	1.77E-12			+3.0 *5*			
7	$^{197}_{79}Au_{118}$	547.5 *3*	7/2+		4.61 ps *+19-13*	4.61E-12						
8	$^{197}_{79}Au_{118}$	583										
9	$^{197}_{79}Au_{118}$	736.7 *3*	7/2+ 2		1.09 ps *+13-9*	1.09E-12			+1.7 *5*			
10	$^{197}_{79}Au_{118}$	855.5 *4*	9/2+		2.67 ps *+25-15*	2.67E-12			+1.5 *6*			
11	$^{197}_{79}Au_{118}$	882										
12	$^{197}_{79}Au_{118}$	888.11 *20*	1/2+ 2									
13	$^{197}_{79}Au_{118}$	936.0 *3*	(5/2+)									
14	$^{197}_{79}Au_{118}$	948										
15	$^{197}_{79}Au_{118}$	1045.1 *3*	(5/2+) 2									
16	$^{197}_{79}Au_{118}$	1120 *10*										
17	$^{197}_{79}Au_{118}$	1150.5 *3*	3/2+,5/2+									
18	$^{197}_{79}Au_{118}$	1217.3 *4*	(3/2+)									
19	$^{197}_{79}Au_{118}$	1220.1 *7*										
20	$^{197}_{79}Au_{118}$	1231.0 *8*	11/2+		0.91 ps *1*	9.1E-13			+2.0 *10*			
21	$^{197}_{79}Au_{118}$	1242.0 *4*	(1/2+)									

From https://nds.iaea.org/relnsd/vcharthtml/VChartHTML.html